# Structured Lineages: Learning from Japanese Structural Design

MoMA

# Structured Lineages
## Learning from Japanese Structural Design

Edited by Guy Nordenson

The Museum of Modern Art, New York

# Contents

## Introduction

# Double Entendre: The Structured Lineages of Japanese Architecture and Engineering

Guy Nordenson

> *Tange Kenzō's understanding of structure was profound. He probably knew more about structure than a lazy structural engineer who did not study well. It's not about ability to calculate, but—he had a brilliant instinct for structure. . . . When we had discussions with Tange, we had to be on our toes.*
>
> —Kawaguchi Mamoru[1]



The essays collected in this book were first presented at The Museum of Modern Art, New York, on April 30, 2016, at the symposium "Structured Lineages," which took place while the exhibition *A Japanese Constellation: Toyo Ito, SANAA, and Beyond*, organized by Pedro Gadanho, was on view in the museum's galleries. Gadanho's exhibition beautifully captured the distinct originality of Japanese architecture, while also tracing the complex networks through which ideas have bounced back and forth, meandered, and even seem to have folded back through time among the contemporary practitioners on view.

What may not have been apparent to the show's visitors, though, is what might be described as the dark matter acting on this architectural constellation: the influence of the famous Japanese engineer Sasaki Mutsurō (b. 1946) and his able protégés, one or the other of whom has worked with almost all of the architects included in the show. The symposium sought to complement the breadth of the exhibition's overview with added historical depth by gathering a group of eminent structural engineers from Japan, Europe, and the United States to reflect on the work of the key Japanese structural engineers of the postwar period, and thereby revealing the ways in which the figure-ground interplay of architecture and engineering—in both education and practice—continues to reshape the evolution of both fields today.

## Schools

In Japan the cultures of architecture and engineering are entirely intertwined. As many of the contributors to this volume note, architects and engineers are educated together during the first phase of their university training.[2] This allows the students to find their way along a full spectrum of roles while imparting a common cultural context to them all. Thus their disciplines and practices are interlocked and overlapping, each visible and translatable to the other (fig. 1).

Both disciplines share the hierarchical character that structures many religious, social, and professional practices in Japanese culture. In a typical Zen Buddhist service, for example, it is not unusual to chant the full lineage of dharma teachers, going all the way back to Buddha himself. The temple of Eihei-ji, which is one of two head temples of the Sōtō Zen sect, was founded in the mountains of Fukui Prefecture by Eihei Dōgen in 1244, shortly after he brought Sōtō Zen from China to Japan. Monks have been taught there continuously ever since, yet Dōgen's name is only midway down the list of teachers chanted at every service.

The Grand Shrine of Japan's other main religion, Shintō, is in Ise, Mie Prefecture. The Ise shrine is dedicated to the sun goddess Amaterasu and is thought to have been originally constructed in 692 (fig. 2). It has since been rebuilt every twenty years, with rare exception. The last reconstruction, in 2013, is considered to be the sixty-second. The building and rebuilding of the Ise shrine is entrusted to a guild of shrine carpenters (*miya-daiku)* whose members span multiple generations and work on several cycles of reconstruction. Each carpenter may teach three or four generations of followers over a lifetime, creating interlocking cycles of influence that ensure the continuous transfer of knowledge over many centuries.

Given that both the Buddhist and Shinto traditions are central to Japanese society and culture, it is no wonder that modern professions and modern institutions such as schools and universities have produced similarly structured lineages. Each constellation overlaps with the others, sharing structures and practices. In the academy the professor occupies a position of honor at the head of a hierarchy of associates, assistants, and students, and in practice the master architect or engineer is assisted by a long line of pupils and younger professionals. You belong to a school, as does your master and his in turn.[3]


**Fig. 1**
**Maekawa Kunio and Le Corbusier in Maekawa's office with Kimura Toshihiko at left in November 1955.**

## Translation

Of course foreign influences have had major effects in Japan ever since the Meiji era, and the forces of globalization are fully present there today. But Japan's rich traditions carry over even into crosscultural encounters. The scholar Michael Emmerich, in the essay "Beyond Between: Translation, Ghosts, Metaphors," enumerates the many Japanese words for "translation":

> A first translation is a 初訳 *shoyaku*. A retranslation is a 改訳 *kaiyaku*, and the new translation is a 新訳 *shin'yaku* that replaces the old translation, or 旧訳 kyū yaku. A translation of a translation is a 重訳 *jū yaku*. A standard translation that seems unlikely to be replaced is a 定訳 *teiyaku*; equally unlikely to be replaced is a 名訳 *meiyaku*, or "celebrated translation." When a celebrated translator speaks of her own work, she may disparage it as 拙訳 *setsuyaku*, "clumsy translation," i.e., "my own translation," which is not to be confused with a genuinely bad translation, disparaged as a 駄訳 *dayaku* or an 悪訳 *akuyaku*. A co-translation is a 共訳 *kyō yaku* or 合訳 *gō yaku*; a draft translation, or 下訳 *shitayaku*, may be polished through a process of "supervising translation," or 監訳 *kan'yaku*, without it becoming a *kyō yaku* or *gō yaku*. Translations are given different names depending on the approach they take to the original: they can be 直訳 *chokuyaku* (literally "direct translation"), 逐語訳 *chikugoyaku* ("word for word translation"), 意訳 *iyaku* ("sense translation"), 対訳 *taiyaku* ("translation presented with the original text on facing pages"), or in the case of translations of works by Sidney Sheldon, Danielle Steel, John Grisham, and other popular American writers, 超訳 *chōyaku* ("translations that are even better than the originals").[4]

If Emmerich's richly nuanced description offers an almost infinite variety of translation, the scholar David Bellos, in *Is That a Fish in Your Ear*, his excellent book-length meditation on translation, suggests a more schematic approach.[5] Arguing that "translation is the enemy of the ineffable," he proposes that translations are always inflected in one direction or another—either "*up* toward a language of greater prestige" or "*down* toward a vernacular with a smaller audience than the source, or toward one with less cultural, economic, or religious prestige." For Bellos, "translations [*up*] toward the more general and more prestigious tongue are characteristically highly adaptive, erasing most of the traces of the text's foreign origin; whereas translations *down* tend to leave



**Fig. 2**
**Ise Shrine, Mie Prefecture.**
Exterior view. 1953

**Figs. 3 and 4**
**Ise Shrine (Naikū), Mie Prefecture. New and Old Auxiliary Building.**
Exterior view. 2013

**Fig. 2**
**Tange Kenzō (architect).**
**Tsuboi Yoshikatsu (engineer).**
**Saint Mary's Cathedral, Tokyo.**
Interior view. Completed 1964

design fee."[2] The building that resulted from this first collaboration is a small structure with a diameter of twenty meters. The shape of the building symbolizes the morning glory, a reference familiar to all of the building's visitors, young and old alike. The library is composed of three distinct geometries: a cone on top, a toroid support in the middle, and a cylinder in the bottom. To design the structure, Tsuboi did both a theoretical analysis based on membrane theory and built a 1:30 physical model, which he used to compare its theoretical and elastoplastic behaviors.
The project was the first example of a reinforced-concrete shell built in Japan after the war, a new typology of structures that Tsuboi described as "one of the finest technological outcomes of this century."[3]



The second example of a shell structure produced from the Tsuboi-Tange collaboration was the Ehime Prefectural Citizens' Hall of 1958, located in Matsuyama City. The structure is basically an inclined, shallow spherical concrete roof, 50 meters in diameter and 12 centimeters thick, tapered down toward the top. As with the Hiroshima library, Tsuboi designed the structure using both theoretical analysis and a scale model. The third shell project they produced together was the Sumpu Kaikan, a gymnasium in Shizuoka Prefecture, completed in 1957. For this building, Tsuboi used the HP shell solution based on a square of 50 meters by 50 meters supported by folded walls. The whole roof covered a surface of 3,500 square meters with a total of 4,506 seats. The design of the Tokyo International Trade Center, built in 1959, is based on the geometry of a spherical surface, but one that has been cut along an inclined plane to produce a very large facade. This project had the largest span of any building in Japan at that time. The spherical shell has a diameter of 120 meters, with a highest point of 31 meters. The dome itself consists of a steel structure weighing 912 tons, covered by concrete plates measuring 4 by 2 meters.

Tsuboi and Tange worked on another important shell structure together in the 1960s: Saint Mary's Cathedral in Tokyo, built in 1964. Their idea for this project was to combine eight reinforced-concrete HP shell roofs into the form of a cross rising from the earth (figs. 1, 2). The concrete shells are left as concrete on the inside and covered with stainless steel on the outside. In the same decade, Tsuboi also designed two shell projects by himself, playing the role of both architect and engineer: the Shimonoseki Municipal Gymnasium in Yamaguchi Prefecture, built in 1963, and the Yumiharidake Observatory in Sasebo City, constructed in 1965 (figs. 3–5).

**Fig. 15**
**Murata Yutaka (architect). Kawaguchi Mamoru (engineer). 12th World Orchids Conference Pavilions, Kanagawa Prefecture.**
Interior view. Completed 1987

**Fig. 16**
**Jaime Pérez (architect). schlaich bergermann partner (engineers). Palacio Vistalegre, Madrid.**
Roof. Completed 2000

**Figs. 17 and 18**
**Jaime Pérez (architect). schlaich bergermann partner (engineers). Palacio Vistalegre, Madrid.**
Exterior views. Completed 2000

**Fig. 19**
**Planinghaus (architects). schlaich bergermann partner (engineers). Movable membrane roof for former casting house Duisburg-Nord, Duisburg.**
Interior view. Completed 2003



More than 270 of these elements were combined to form the final roof. Even the cushions' details were complex, involving tubes for inflation, which can be seen in photos, and stiffeners and belts to reinforce the film. Given how much had to be invented in such a short time (the engineer invents; the scientist discovers), the project was a most impressive success.

Kawaguchi moved on to even larger pneumatic structures in the late 1980s. For the World Orchids Conference he designed an 80-meter-diameter dome and a 100-meter-long free-form building (fig. 14). An ingenious design allowed steel cables to carry the main tension forces. Imagine a primary grid made of steel cables and a secondary 10 by 10 centimeter mesh that fills in the gaps between these main cables. A large polyester film panel was placed below these layers and then inflated: a surprisingly quick and economic and, again, most impressive solution (fig. 15).

Consciously or unconsciously, many recent roof designs were inspired by Kawaguchi's earlier inflated structures. The movable cover of the bullfighting ring Palacio Vistalegre, in Madrid, is an inflated cushion 50 meters in diameter (fig. 16). It is supported by cables on winches and can be moved up and down 11 meters (figs. 17, 18). Although it was built in 2000 with the modern materials at our disposal—PVC-coated polyester for the top membrane and ETFE foils supported on a steel-cable net for the lower membrane—the fundamental principle of the design is familiar from Kawaguchi's work. Another example is the open-air theater Giesshalle in Duisburg, Germany (fig. 19), which is essentially a moveable roof that runs on rails, again with inflated cushions of ETFE foil. These are some of the lineages that connect Kawaguchi to our work today.

So far I have focused primarily on Kawaguchi's built projects, but his academic research also forms an important part of his legacy. He became Professor at Hōsei University in Tokyo in 1972 and was highly esteemed for his hands-on approach to both teaching and research. Among his many research projects, one of the most fascinating is his quest to find what he called "the shallowest possible form."[8] From experience, Kawaguchi knew that the hemisphere works well for domes and inflated structures but also is a waste of space because of its great height in the center. A seemingly obvious alternative, the ellipsoid, would not

Saitō named this approach “archi-neering” because it’s a hybrid of architecture and engineering. He says that it’s crucial to have both, so that the one can inspire the other. Sometimes the engineer comes up with an idea and the architect polishes it; sometimes the architect comes up with the basic idea and the engineer makes it possible. The crucial thing is that it’s always a dialogue. And his belief in collaboration does not mean he idealizes the process; he experienced firsthand the friction—intense discussion, and sometimes fights—between Tange and Tsuboi. But this friction is an important part of collaboration, and the masterpiece that resulted continues to be an inspiration for future generations of architects and engineers.

Many of the projects Saitō worked on in the 1960s and ’70s were more conventional, classical designs. A typical example of this period is the gymnasium of Iwate Prefecture (fig. 1). Saitō classifies these structures as thoroughbred structures, which, in the terminology he invented, refers to a structure that is inspired by engineering. It’s a rational structure, usually following a design based on experimental models and rudimentary calculations, with a sort of unity between the form of the structure and its loading capacity.

Indeed, models were very important at the time. Not only architectural models, which helped designers understand the form of these buildings, but also structural models, which helped them understand the structure’s complex geometry and behavior. In the 1970s, calculation capacities were still relatively rudimentary (remember that the first Apple computer did not appear until 1975), and the analysis of complex geometries still relied on physical modeling. But even now, Saitō’s emphasis on models is an important part of his legacy. He still thinks that it’s important to do physical models to get a feeling of the physical behavior of a structure, although of course you also have to use the modeling power of the computer.

An important milestone for Saitō came in 1978. That year, a series of hybrid projects, as he called them, marked a turning point in his conceptual thinking. One of the innovations he introduced was the notion of a beam-string structure. Traditionally, engineers have understood a beam to work in bending, and a truss in pure compression and tension. Saitō’s idea was to mix both things, creating a system that works a little bit in bending and a little bit in tension—in some ways taking advantage of the best of both

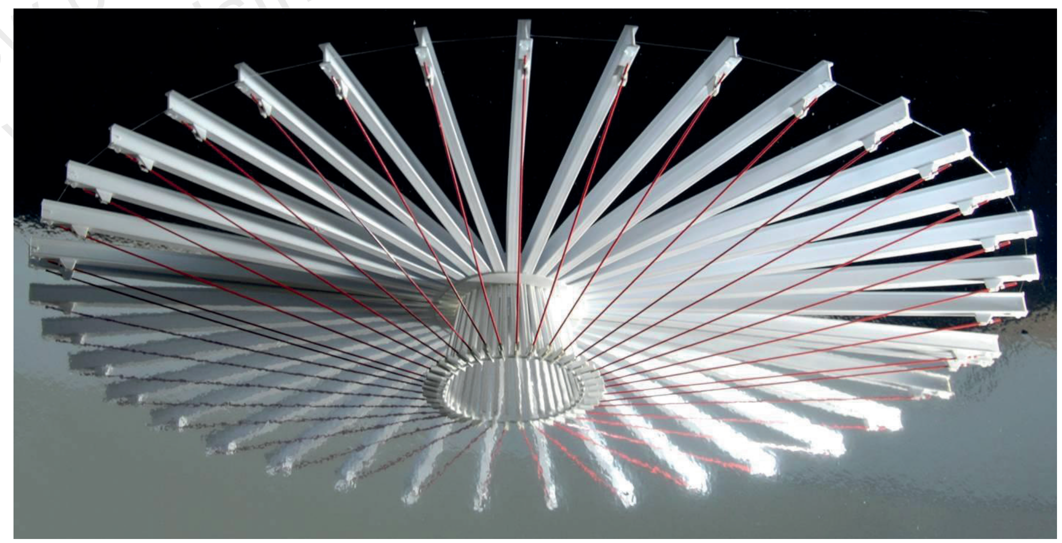


**Fig. 1**
**Kobayashi Yoshio (architect).**
**Saitō Masao (engineer).**
**Iwate Gymnasium. Iwate Prefecture.**
Interior view. Completed 1967

**Fig. 2**
**Kobayashi Yoshio (architect).**
**Saitō Masao (engineer).**
**Faraday Hall, Nihon University, Tokyo.**
Completed 1978

**Fig. 3**
**Kobayashi Yoshio (architect). Saitō Masao (engineer). Sakata Municipal Gymnasium, Yamagata Prefecture.**
Interior view. Completed 1991

**Fig. 4**
**Ikehara Yishiro (architect). Saitō Masao (engineer). Karato Fish Market, Yamaguchi Prefecture.**
Interior view. Completed 1992



systems' structural behaviors. Saitō's design for Faraday Hall at Nihon University, for example, includes a circular space with an open span of 18.5 meters created by thirty-six radial beams that have been posttensioned by the same number of cables (fig. 2). Saitō's father was a famous archer, and it is easy to understand this as the inspiration of the beam-string structure: it is nothing less than a bow, a string and an arrow. Nevertheless, such a design is extremely complex from an engineering point of view because its structural behavior is nonlinear, and so the process of mounting and loading the structure, as well as its internal load adjustment, must become part of the structural and architectural design. This important step in engineering became possible with the increasing power of computers to perform structural calculations, opening up a new world of possibilities.



In the following years, Saitō built several more of these beam-string structures. These include the Sakata Municipal Gymnasium, in Yamagata Prefecture, which has a roof spanning 53 meters (fig. 3). This design beautifully illustrates Saitō's search for lightness that is not only physical but also visual. When you are inside the space, the thin cables almost disappear, and the directional light, which enters from the side, below the beam-string structure, gives the impression that the roof levitates above the gymnasium. Another example, one of my personal favorites, is the Karato Fish Market, built in 1992 (fig. 4). This structure is not typical for Saitō because it uses concrete. It's a heavy, very sculptural structure. Yet in this case, the form of the roof feels appropriate, almost a metaphor for what happens under it—fish, too, have very sculptural forms, so the roof can be seen as a sort of projection of the building's interior world. In that sense, it is a poetic structure, but it's also a very rational one. The concrete is in compression, and the cables are, of course, in tension. The form is the expression of the bending moments in the structure; the concrete and the cables are the externalization of forces. On the inside, the strings pass under the concrete and cross at its edge, allowing them to form a cantilever structure (fig. 5). This cantilevering principle is used recurrently in Saitō's designs in order to increase their spans.

The Anō Dome in Kita-Kyūshū (Fukuoka Prefecture), completed in 1995, is another example of this type of structure, which uses a beam string plus a cantilever (figs. 6, 7). This structure's appearance is more typical for Saitō's work because it's light and transparent, appearing almost as if it was floating. Rather than concrete, the materials used are timber, membrane, and

The following is an edited transcription of the panel discussion that took place on the morning of April 30, 2016, at The Museum of Modern Art in New York, as part of the “Structured Lineages” symposium held in conjunction with the exhibition *A Japanese Constellation: Toyo Ito, SANAA, and Beyond*. The participants were Seng Kuan, Marc Mimram, Laurent Ney, and Mike Schlaich; Sigrid Adriaenssens moderated.

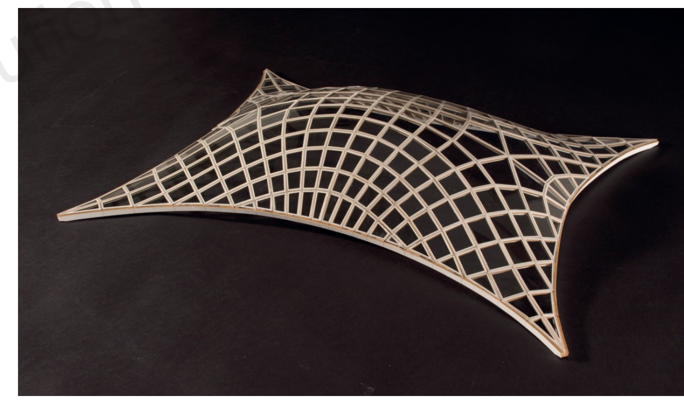
**Figs. 24–26**
**Itō Tōyō (architect).**
**Sasaki Mutsurō (engineer).**
**Meiso no Mori (Forest of Meditation) crematorium, Gifu Prefecture.**
Exterior and interior views.
Completed 2006

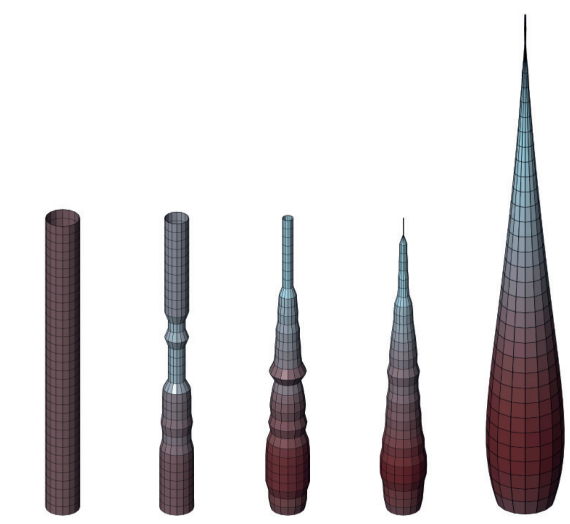


**Fig. 27**
**Skidmore, Owings & Merrill (SOM). Shape generated with heavy soap-film tool**

**Fig. 28**
**Skidmore, Owings & Merrill (SOM). Continuum shell**

**Fig. 29**
**Skidmore, Owings & Merrill (SOM). Gradient optimization**





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